Diaphragm Pacing

Anthony F. DiMarco, MD

KEYWORDS

• Diaphragm pacing • Spinal cord injury • Ventilatory support • Mechanical ventilation

KEY POINTS

- Diaphragm pacing is a useful and cost-effective alternative to mechanical ventilation.
- Benefits of diaphragm pacing include improved mobility, speech, olfaction, and quality of life.
- Diaphragm pacing is cost-effective, being less expensive compared with long-term mechanical ventilation.
- Diaphragm has few side effects and complications.

INTRODUCTION

Chronic ventilatory support is most commonly required for management of patients with respiratory failure consequent to severe dysfunction of the lungs or respiratory muscles. These patients are typically maintained on either traditional mechanical ventilation (MV) via tracheostomy tube or noninvasive methods. A unique category of patients with chronic respiratory failure, however, are those in whom the lungs, chest wall, and respiratory muscles are fully intact. These patients experience chronic respiratory failure due to lack of neural input from the central nervous system to the major inspiratory muscles. These include patients with central hypoventilation syndrome (CHS)[1,2] in whom there is inadequate drive from the respiratory centers in the medulla and patients with cervical spinal cord injury (SCI) in whom there is interruption of nerve impulses from the respiratory center to the inspiratory muscles.[3–11] Because the respiratory neuromuscular apparatus is otherwise normal, these patients are candidates for an alternative method of ventilatory support involving the application of electrical stimulation to the phrenic nerves, that is, diaphragm pacing (DP).

RESPIRATORY PHYSIOLOGY

The diaphragm, which is a thin dome-shaped sheet of skeletal muscle separating the thoracic and abdominal cavities, is the primary muscle of inspiration (Fig. 1). This is illustrated by patients breathing comfortably at rest with singular function of the diaphragm alone. The muscular fibers of the diaphragm originate from the abdominal wall and lumbar vertebrae posteriorly, the xiphoid process and floating ribs anteriorly, and the lateral rib cage laterally and insert on a central tendon. The diaphragm consists of anteriorly located costal fibers and posteriorly located crural fibers. The vena cava, esophagus, and aorta pass through the diaphragm posteriorly.[12]

Normal inspiration is associated with contraction of both the diaphragm and inspiratory intercostal muscles lasting approximately 1 second, 8 times per minute to 12 times per minute. The inspiratory intercostal muscles are primarily located in the upper 6 interspaces. Contraction of the inspiratory muscles results in the development of a negative intrathoracic pressure causing inhalation of air into the chest. After diaphragm relaxation, exhalation occurs passively due to the positive pressure developed by lung and chest wall recoil pressure. The function of the intercostal muscles is illustrated by the contraction of the diaphragm alone resulting in paradoxic inward movement of the anterior rib cage. This phenomenon is most significant in infants with an immature flexible rib cage but does not interfere with adequate tidal volume generation in adults in whom the rib cage is much less compliant.

Potential Conflict of Interest: Dr A.F. DiMarco is stakeholder in Synapse Biomedical, in Oberlin, Ohio, a manufacturer of diaphragm pacing systems.
Physiology and Biophysics, Case Western Reserve University, MetroHealth Medical Center, 2500 MetroHealth Drive, Cleveland, OH 44109, USA
E-mail address: afd3@case.edu

Clin Chest Med 39 (2018) 459–471
https://doi.org/10.1016/j.ccm.2018.01.008

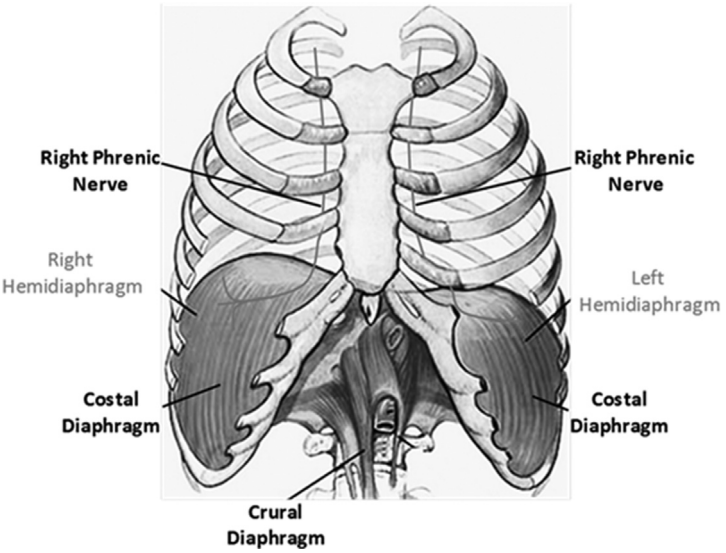

Fig. 1. Schematic drawing of the human diaphragm.

Relevant to the anatomic location of cervical spinal cord lesions, the diaphragm is innervated by a single right phrenic nerve and single left phrenic nerve, each of which is supplied by cervical spinal nerves C3, C4, and C5. The phrenic motoneurons, however, are most plentiful at the C4 level. Each phrenic nerve trifurcates just above the dome of the diaphragm as it enervates this muscle.

With regard to potential candidates for DP, virtually all patients with CHS and secondary chronic respiratory failure are potential candidates for this modality because the phrenic nerve/diaphragm neuromuscular apparatus is fully intact. Patients with cervical SCI, however, need to be carefully evaluated to assess the integrity of the phrenic nerves. Patients with cervical lesions limited to the C3 level and higher are usually excellent candidates for DP. In patients with damage to the phrenic motoneuron pools at the C4/C5 level and/or direct damage to the phrenic nerves, however, DP will not be successful. It is also important to point out that bilateral phrenic nerve integrity is necessary for successful DP.

MECHANICAL VENTILATION VERSUS DIAPHRAGM PACING—CLINICAL CONSIDERATIONS

In the management of acute and chronic respiratory failure, positive-pressure MV is a life-sustaining modality. MV can be applied via tracheostomy tube or less invasive means via nasal/facial mask appliances. In patients with CHS in early childhood, tracheostomy may be preferred due to the potential development of midface hypoplasia with mask ventilation.[13] In addition, these devices can be uncomfortable and poorly tolerated in many individuals. Given that this is life support device, MV via tracheostomy may be preferable.

With regard to SCI and excluding those who die at the scene, there are approximately 17,500 new cases per year, of which more than half occur at the cervical level.[14] Although a majority of tetraplegics require at least temporary MV via tracheostomy, most are successfully weaned from these devices. Nonetheless, as many as 400 to 500 per year new patients require chronic mechanical ventilatory support. Importantly, ventilator dependency is an independent negative prognostic factor for long-term survival. During the first-year postinjury, there is as much as a 40-fold increase in mortality that remains elevated at 2-fold to 3-fold in subsequent years. Compared with a normal 20 year old, life expectancy for patients surviving at least 1 year postinjury is markedly diminished, from 60 years to only 18 years. In high tetraplegics who do not require MV, life expectancy is significantly higher, at 35 years.[14]

In properly selected individuals, DP provides an important alternative to MV with significant advantages (**Box 1**).[4,5,10,15–20] Compared with MV, most patients describe an improved sense of well-being and overall health. This could occur consequent to these patients engaging their own inspiratory muscles and sensing more normal breathing. Patients also describe the benefit of no longer requiring connection to an external machine and attached tubing. Negative-pressure ventilation may reduce the incidence of barotrauma and also have